§ 11. Theoretical Analysis of Structure of Radial Electric Field in Helical Systems

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The internal transport barrier has been found in electron resonance heating (ECRH) plasma in the compact helical system (CHS), and the steep gradient of the radial electric field is observed in the core plasma. Furthermore, the electric pulsation was observed related with the bifurcation of the radial electric field in CHS device. Recently, the internal transport barrier is also obtained in LHD. To examine the existence of the transport barrier in the experimental conditions of helical plasmas, the important issue is the study of turbulent transport and neoclassical energy transport so as to understand the formation of the internal transport barrier. In order to analyze the structure of the electric field quantitatively, the self-consistent transport study is done in which both the electric field bifurcation and suppression of the anomalous transport are included. The magnitude and the spatial distribution of the transport reduction are studied. The hard transition of E_r which induces the steep gradient is examined. We examine the parameter region where the neoclassical transport is dominant compared with the anomalous transport when we adapt the model for anomalous diffusivities to describe the turbulent plasma. We call this transition a hard-type one when the multiple solutions for the ambipolar E_r exist and the transition occurs between them. The neoclassical diffusivities are found to have a peak near the domain interface where the electric field vanishes. When the electron temperature is much higher than the ion temperature, one solution of the ambipolar electric field may exist. In this case, the spatial transition of E_r becomes smooth. We call this a soft transition. The two types of transition are compared, and the effect on transport reduction is examined. The prediction of the self-generated oscillation is also done in helical plasmas.

The cylindrical coordinate is used and the r-axis is taken in the radial cylindrical plasma. At first, we set the constant value for the anomalous particle diffusivity. The stationary solutions of the radial electric field are shown in Figure 1. The profiles of the density and the temperature are obtained. At the point $\rho\sim0.5$, the transition of the radial electric field is shown. The circles in figure 1 show the values of the electric field which satisfy the local ambipolar condition for the calculated profiles of the density and the temperatures. In the inner region, the steady-state local ambipolarity condition can have three solutions for E_r. In the case of Figure 1, the electron root ($\rho<\rho_T$) for E_r is sharply connected to the ion root ($\rho>\rho_T$) with a thin layer between them. The transition points should be determined by the Maxwell construction. The peak at the transition point is found in the profile of the radial electric field gradient.

The transport barrier is clearly obtained for the both channels of the neoclassical transport and the anomalous transport in both T_e and T_i profiles. At the transition point, the suppression of the anomalous transport is obtained due to the strong electric field shear. The neoclassical diffusivities of electrons χ_e^{NEO} and ions χ_i^{NEO} are also obtained. When the spatial transition occurs, the electric field goes across zero. Therefore, the neoclassical diffusivities have a peak near the surface where the relation $E_r\sim0$ holds. In the parameter region examined here, the neoclassical transport is found to be dominant compared with the anomalous transport, since the anomalous transport is suppressed due to the moderate gradient of the radial electric field. In the inner region from the transition point, the neoclassical transport is reduced due to the large positive radial electric field. Therefore, total suppression can be seen and the clear transport barrier is shown.

Next, we also adapt the anomalous transport model for the particle diffusivity. In this case, the self-generated oscillation of the radial electric field is examined in the edge region. The oscillation can be also obtained in the temporal evolutions of the density and the electron and ion temperatures. The radial transition occurs from ion root (in a inner region) to electron root (in a edge region).

In this work, the structure of the radial electric field in helical plasmas is theoretically studied. The temporal and spatial evolutions of plasma density, temperature and radial electric field are examined. A numerical formula is employed to determine the neoclassical components of particle and heat fluxes in helical plasmas. The analysis is done using one-dimensional transport model equations. The clear transport barrier can be seen in the parameter region in which the neoclassical transport is dominant compared with the anomalous one. The temporal oscillation of E_r is also obtained in the edge region due to the bifurcation characteristic of the radial electric field.

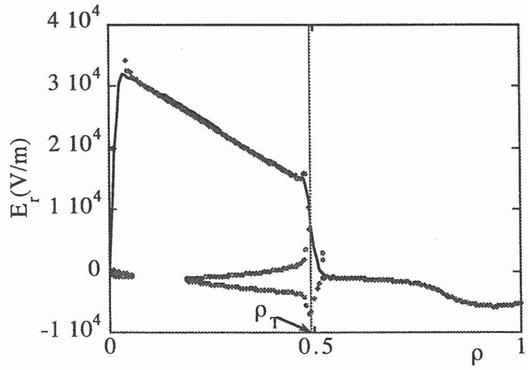

Fig.1 Profile of the radial electric field

Reference

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